AFOSR - TR - 77 - 0317

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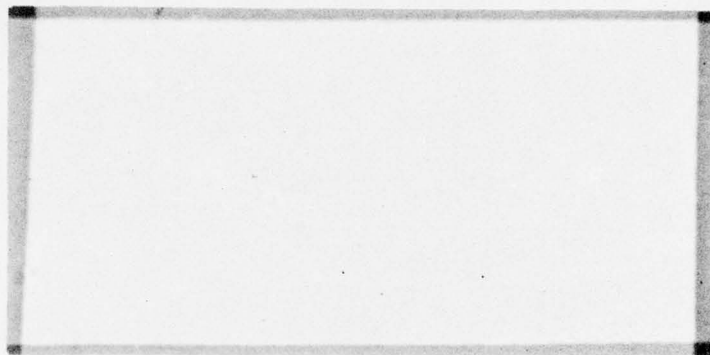See 1473
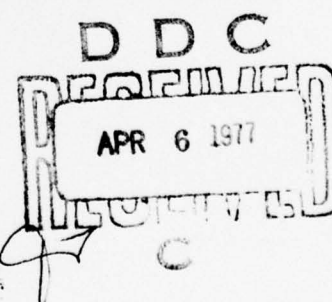
1910 Forest Drive • Annapolis, Md. 21401 • (301) 268-6150
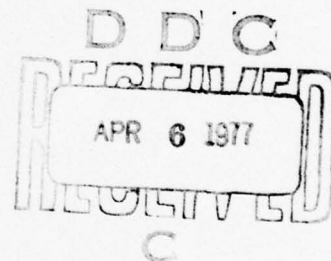
FINAL REPORT

RESEARCH ON PARACHUTE OPENING

BY

PETER R. PAYNE
AND
E. G. U. BAND

FOR

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
BLDG. 410, BOLLING AFB, D.C., 20332

CONTRACT NO. F44620-76-C-0020

Payne inc.

TABLE OF CONTENTS

ABSTRACT

This report summarizes work carried out under contract number F44620-76-C-0020 in connection with parachute opening theory. Contributions were made in the following areas.

      (a)   Prediction of fabric porosity effects.

      (b)   Calculation of the external and internal pressure fields during inflation.

      (c)   Calculation of the canopy shape and stress distribution during inflation.

These three elements, taken together, cover the problem, but they were not integrated into a complete predictive methodology because of lack of time.

The analogous problem of the opening of a two-dimensional hinged plate was also studied, both experimentally and theoretically. The problem of the inviscid flow field inside such an inflating wedge was solved exactly, in closed form, and agreed well with experiment.

Most of the reports written during this study will be published in the open literature.

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DISCUSSION

Fabric Porosity

In Reference 1* it was shown that existing methods of predicting the flow through a fabric or gauze were unsatisfactory (the "coefficients" are not constants) because they ignored viscosity. It was shown that the available experimental data rather follows a law first enunciated by Osborne Reynolds; namely

$$\Delta p = K_1 U^2 + K_2 U \tag{1}$$

where Δp = the pressure drop across the cloth
U = volume flow/cloth area
K_1 = the dynamic pressure coefficient
K_2 = the viscous pressure coefficient

Reference 1 presents equations for K_1 & K_2. Figure 1 shows how K_1 varies with the fabric's geometric porosity α_G, through six orders of magnitude. Figure 2 shows how the viscous coefficient varies with the parameter

$$\left(\frac{n\ell}{A}\right) \frac{1}{\alpha^2}$$

where n/A = number of holes per unit area
ℓ = cloth thickness
α = aerodynamic porosity = $1/(1+\sqrt{2K_1/\rho}\,)$

Figure 3 shows the relationship between geometric porosity α_a and the aerodynamic porosity α to be roughly one to one at the values of interest to parachute designers.

The analysis of Reference 1 is also shown to be applicable to thick felt filters multi-layer sintered gauzes, and similar materials.

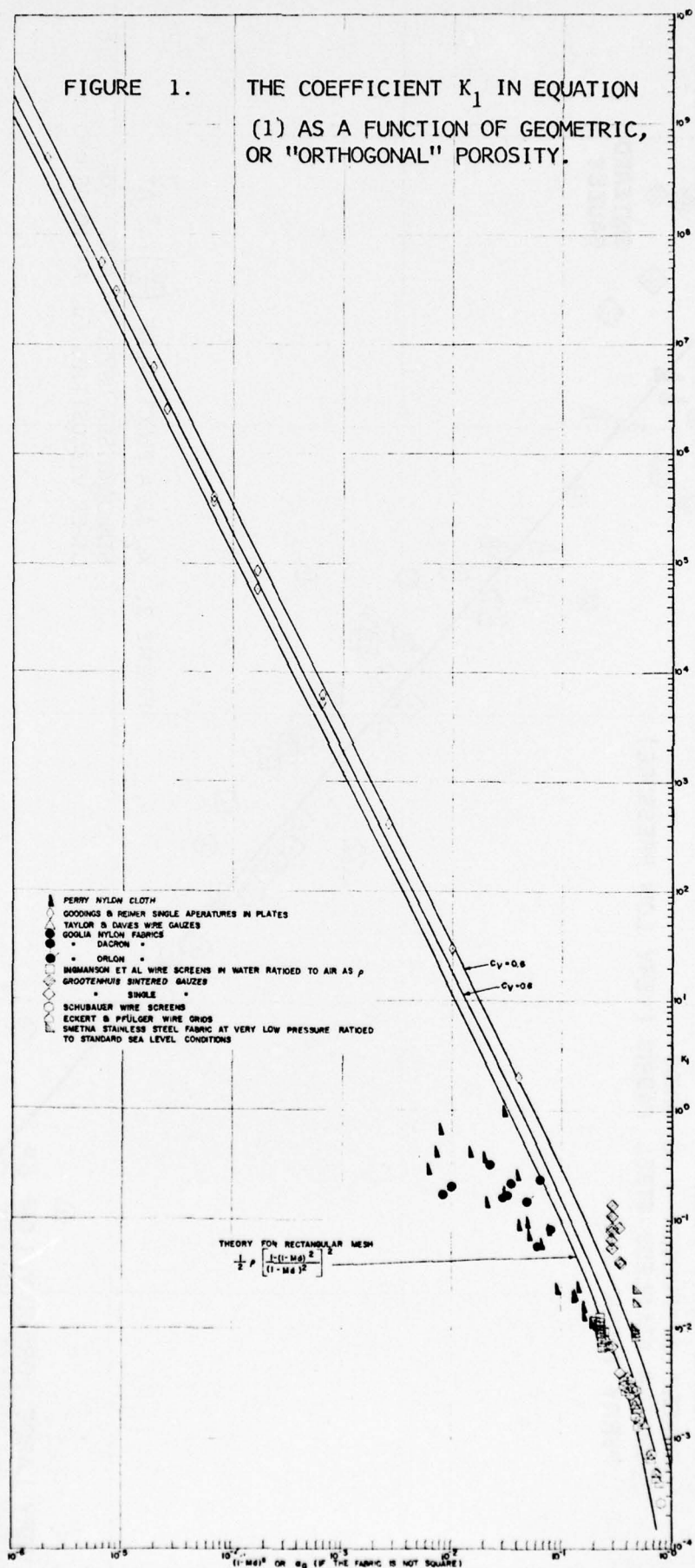### The Pressure Fields Inside & Outside an Inflating Canopy

Reference 2* computes the unsteady inviscid flow field inside an inflating canopy of idealized (cylindrical) shape, and obtains a closed form solution which compares well with the meager experimental data available. Streamlines for the simple solution of constant cavity length (for which normalized stream-lines are constant) are shown in Figure 4.

The problem of the external pressure field is solved approximately in Reference 3, by the use of a time-varying, three-dimensional, sink-source pair to develop the canopy shape. Figure 5 shows the general flow field developed. Figure 6 is developed from some experimental observations by Klimas, during inflation of a model canopy, and Figure 7 shows that the theory gives generally similar results.

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*To be published in the AIAA Journal of Aircraft.

FIGURE 1. THE COEFFICIENT K_1 IN EQUATION

(1) AS A FUNCTION OF GEOMETRIC, OR "ORTHOGONAL" POROSITY.

$C_V = 0.6$

$C_V = 0.6$

PERRY NYLON CLOTH
GOODINGS & REIMER SINGLE APERATURES IN PLATES
TAYLOR & DAVIES WIRE GAUZES
GOOLIA NYLON FABRICS
" DACRON "
" ORLON "
INGMANSON ET AL WIRE SCREENS IN WATER RATIOED TO AIR AS ρ
GROOTENHUIS SINTERED GAUZES
" SINGLE "
SCHUBAUER WIRE SCREENS
ECKERT & PFÜLGER WIRE GRIDS
SMETNA STAINLESS STEEL FABRIC AT VERY LOW PRESSURE RATIOED
TO STANDARD SEA LEVEL CONDITIONS

THEORY FOR RECTANGULAR MESH
$$\frac{1}{2} \rho \left[\frac{1-(1-M\delta)^2}{(1-M\delta)^2} \right]^2$$

K_1

$(1-M\delta)^2$ OR σ_g (IF THE FABRIC IS NOT SQUARE)

FIGURE 2. K_2 AS A FUNCTION OF $\left(\frac{n\ell}{A}\right)/\alpha^2$ AT STANDARD SEA LEVEL IN AIR. FOR OTHER VISCOSITIES (μ) RATIO AS μ
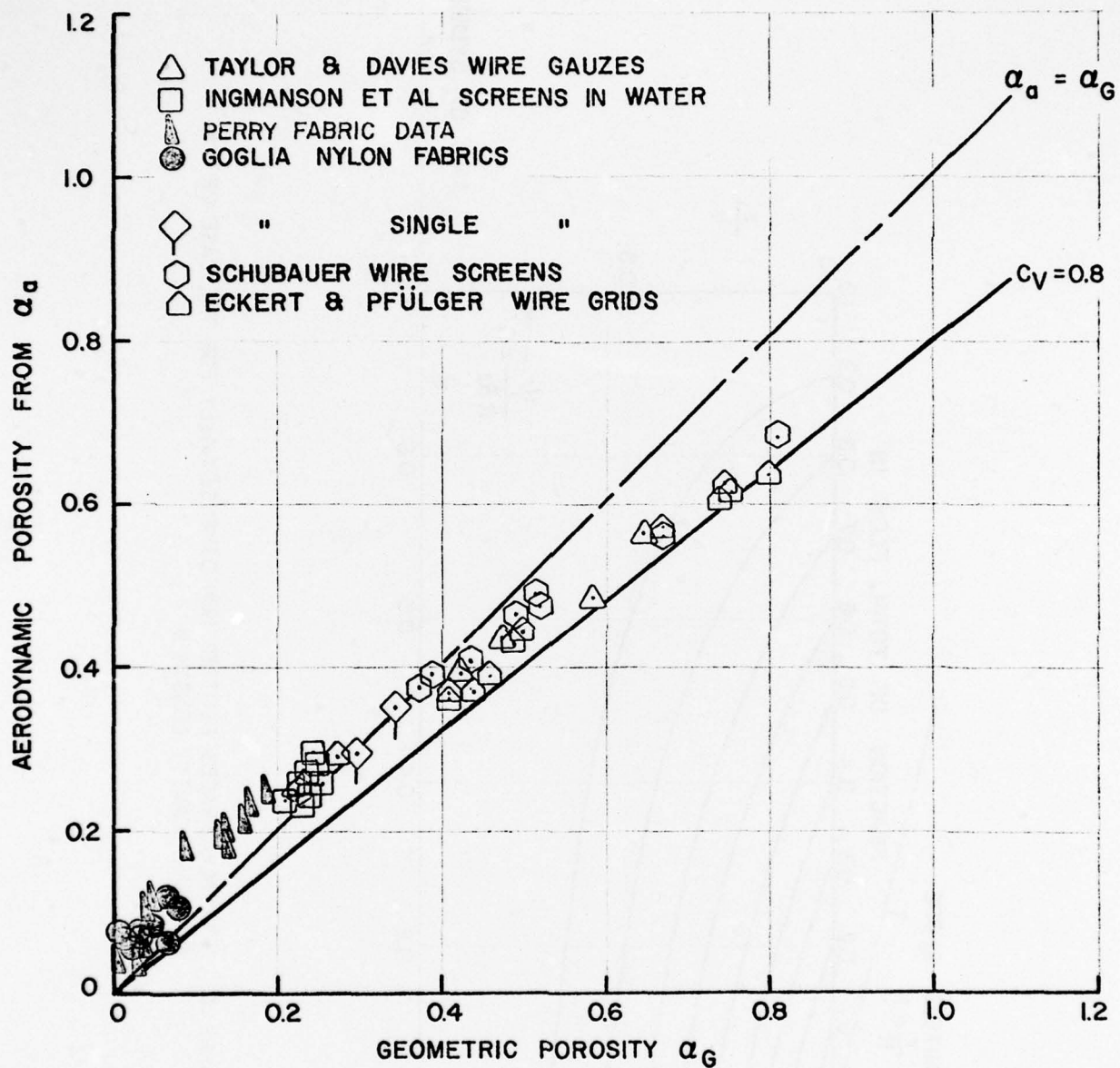
FIGURE 3. COMPARISON BETWEEN GEOMETRIC POROSITY AND THE VALUE DEDUCED FROM

$$\alpha_a = 1/\left(1 + \sqrt{\frac{2}{\rho} K_1}\right)$$
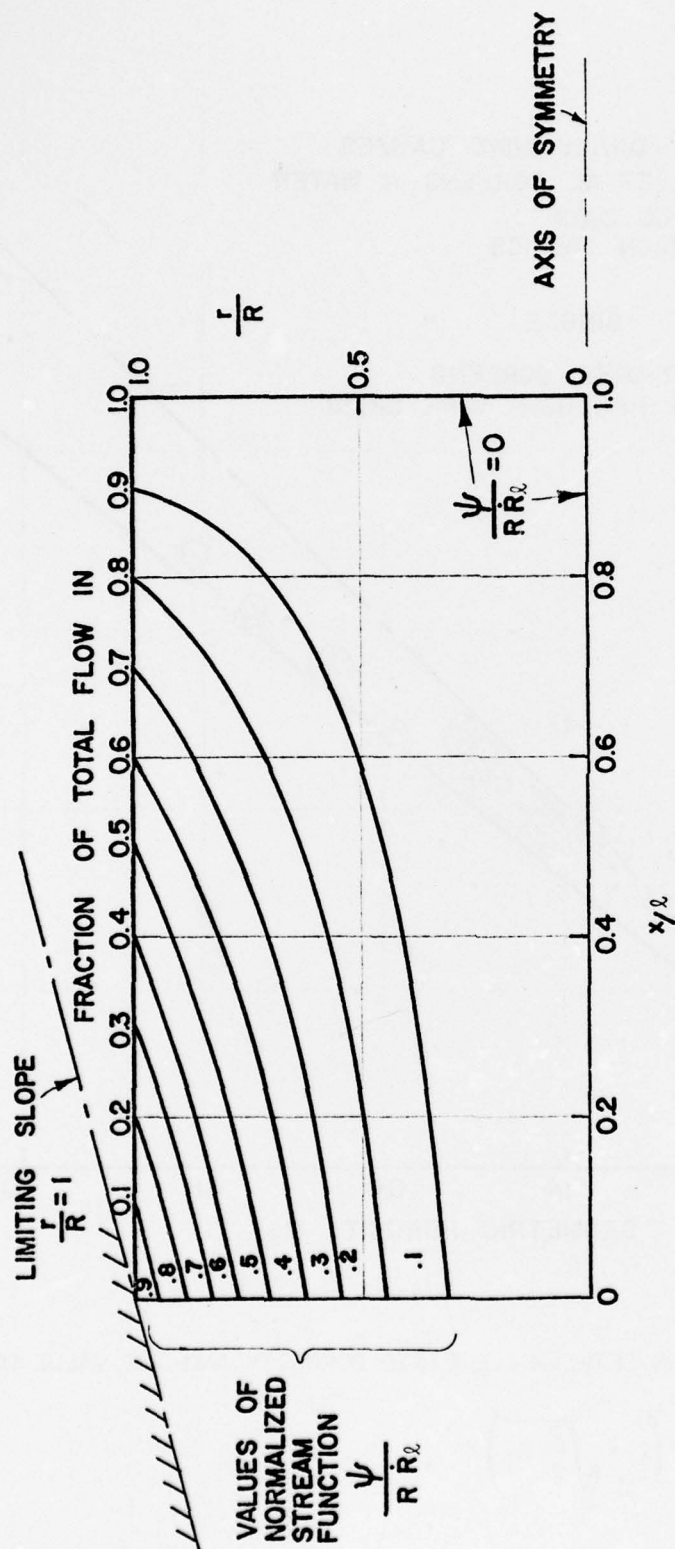
5

FIGURE 4. STREAM SURFACES PLOTTED NON-DIMENSIONALLY FOR THE CASE OF CONSTANT CAVITY LENGTH ℓ
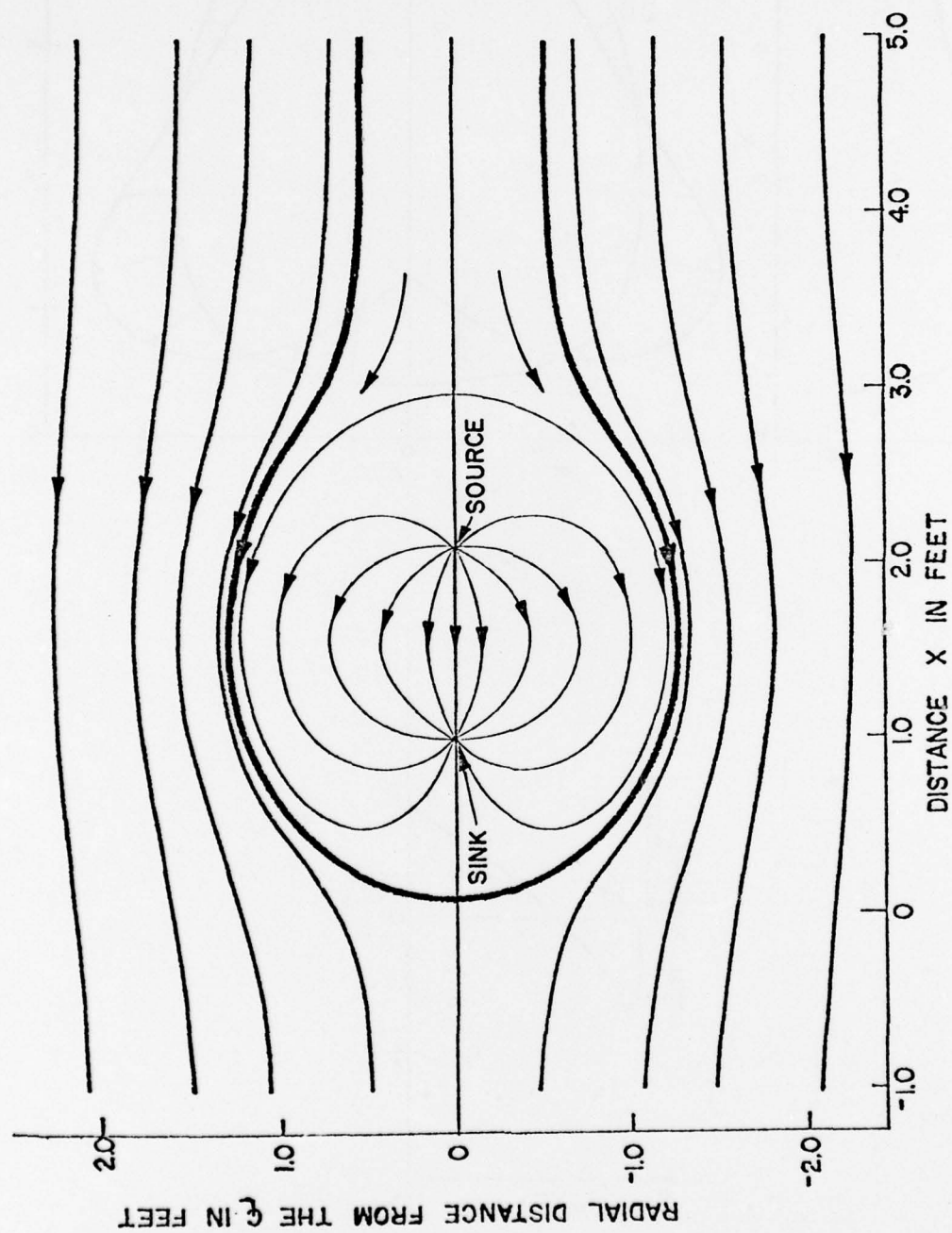
FIGURE 5. STREAMLINES AROUND AN OPENING CANOPY, MODELED WITH AN UNEQUAL SOURCE AND SINK PAIR, OF VARIABLE INTENSITY.
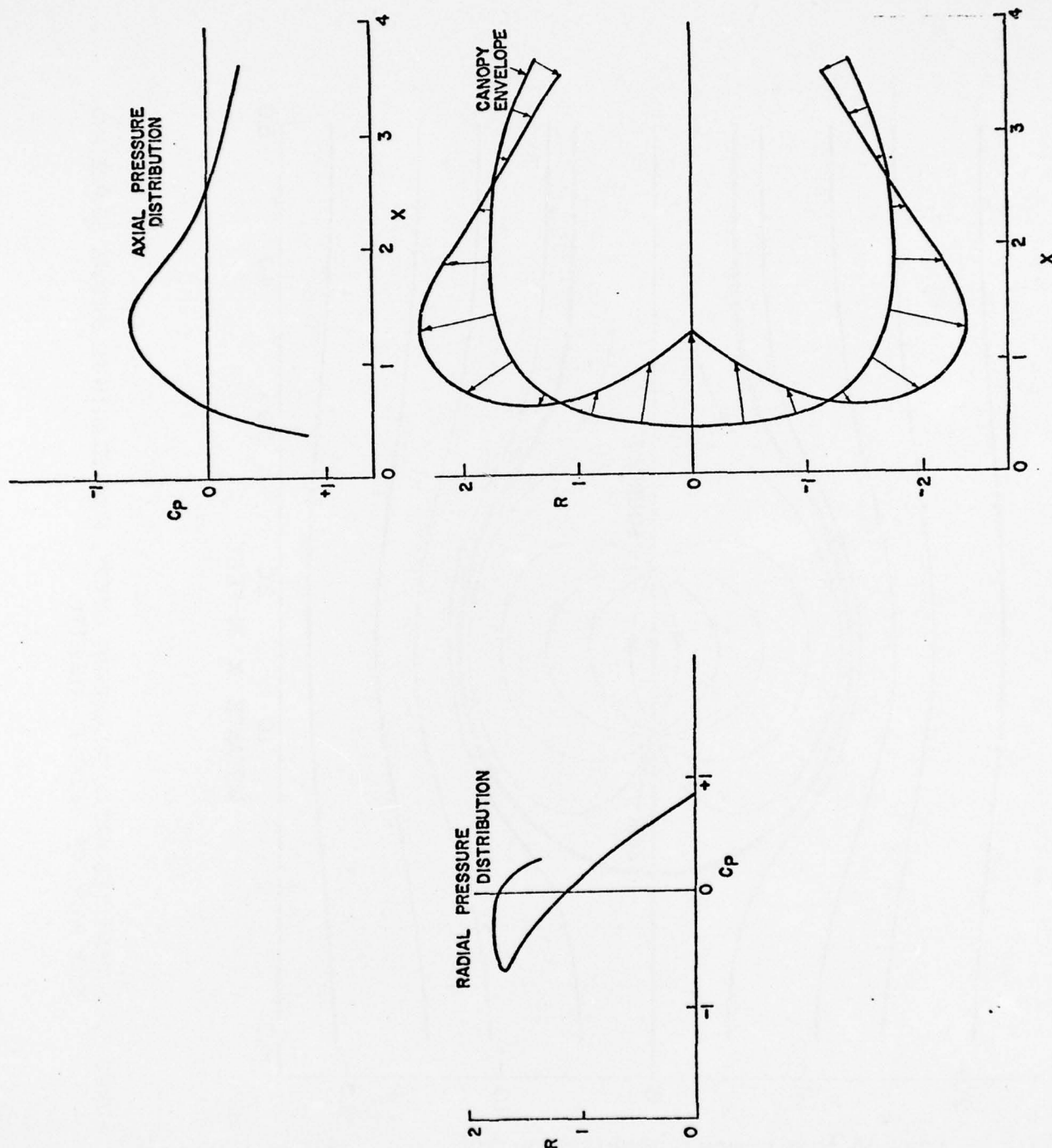
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FIGURE 6.   COMPUTED PRESSURE DISTRIBUTION OVER AN EXPANDING CANOPY AT
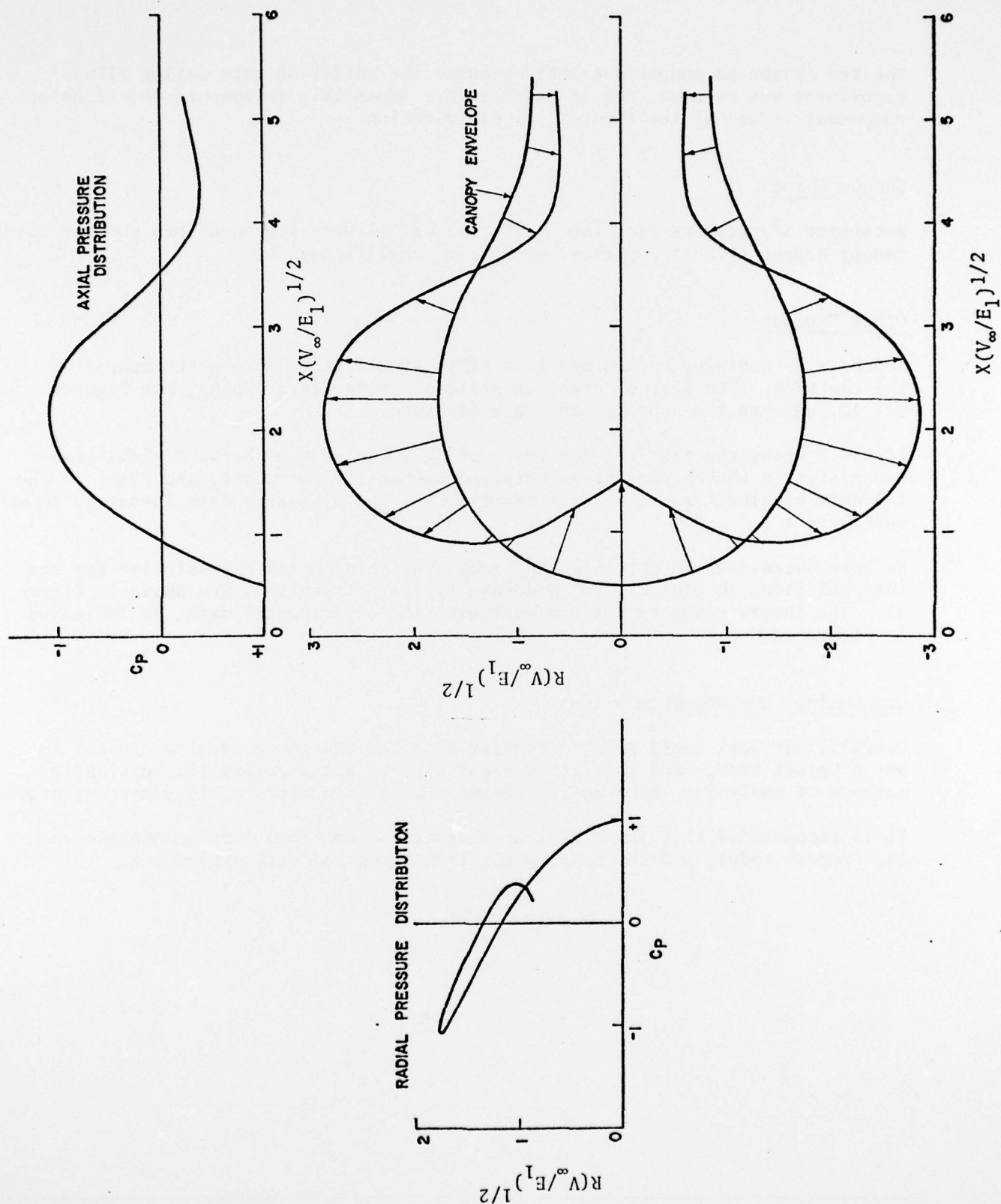T = .05 SEC. FOR THE EXPERIMENTS OF KLIMAS[4].

FIGURE 7. STATIC PRESSURE DISTRIBUTION OVER "BEST" GENERATED SHAPE IN INVISCID FLOW FOR COMPARISON WITH FIGURE 6.

The two cannot be compared exactly because the inflation rate during Klimas'
experiment was unknown, and it is therefore impossible to compute the transient
component $\partial\phi/\partial t$ of the theoretical distribution.

Canopy Shape

Reference 5* presents (for the first time we believe) the equations for computing
canopy shape, without empirical geometric simplifications.

Other Studies

Appendix A contains a complete list of reports written during the course of
the contract. The last of these is still awaiting final typing, but Figures
8 - 12 indicate the scope of the investigation.

Figure 8 shows the test rig for the opening wedge, rigged between plexi-glass
end plates in the University of Maryland subsonic wind tunnel, and Figure 9 the
raw data obtained from a typical experiment. The processed data format is shown
in Figure 10.

We were successful in obtaining an exact (inviscid) transient solution for the
internal flow, in closed form, and some typical streamlines are shown in Figure
11. The theory seems to conform well with the experimental data, as indicated
in Figure 12.

Conclusions and Recommendations

Overall, our work would seem to confirm that the parachute opening process is
not a "black art", and that its various aspects are amenable to the classic
methods of analysis. Substantive advances have been made in all important areas.

It is recommended that these various elements be combined into a complete open-
ing process model, and the model predictions compared with experiment.

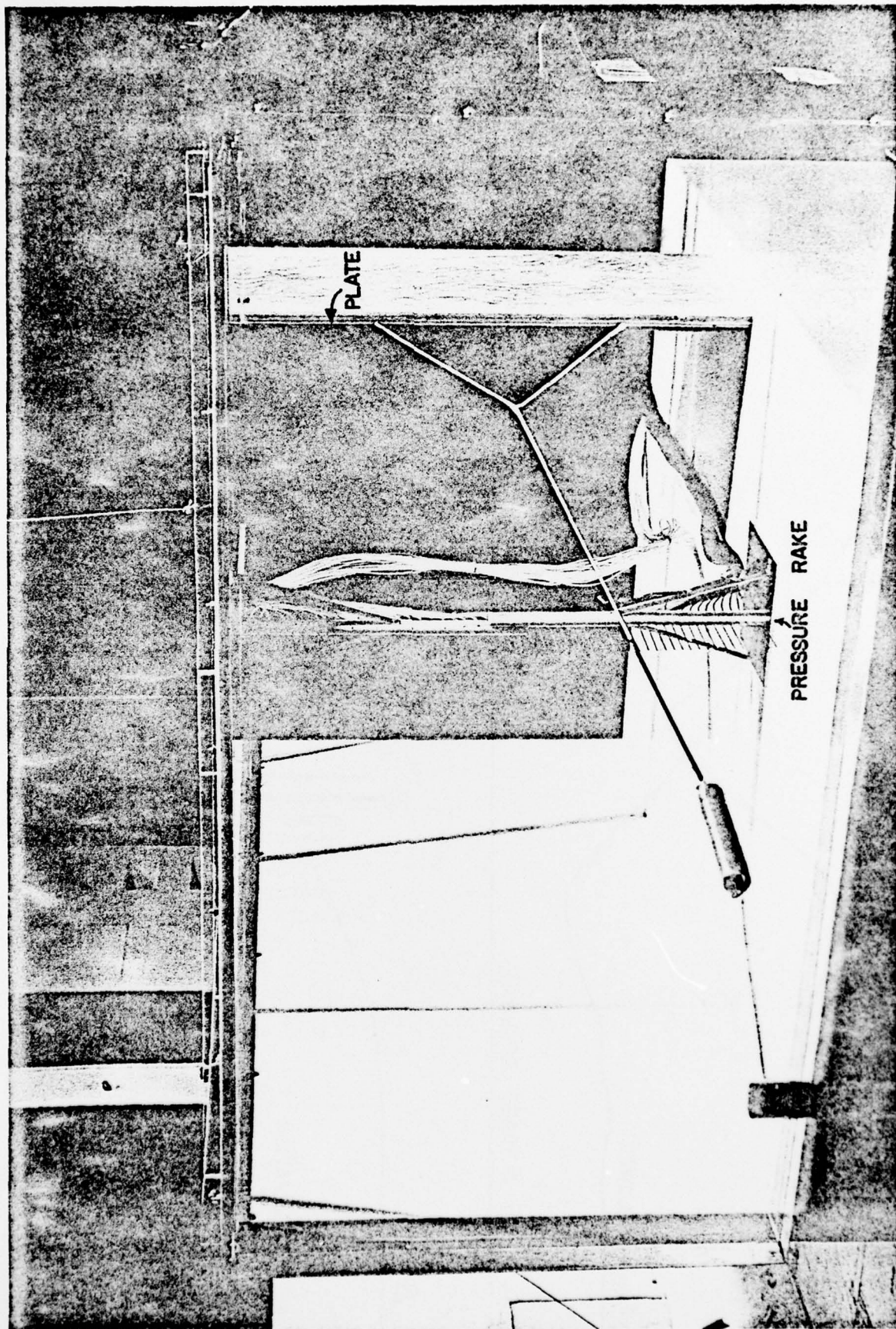
*Submitted for publication.

Figure 8. Two-Dimensional Test Section Showing Experimental Set Up and Pressure Survey Rake.
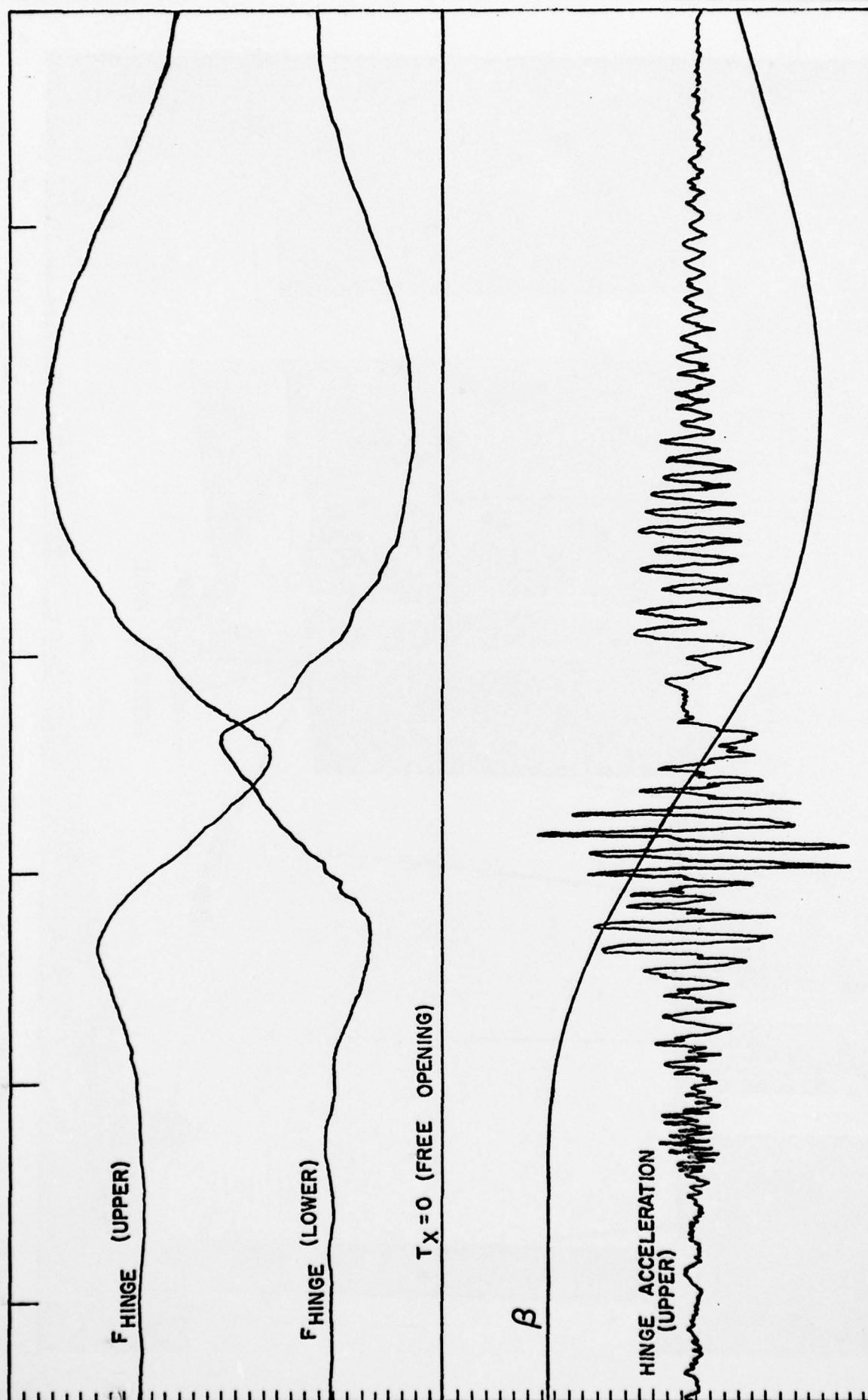
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FIGURE 9. RAW DATA FOR THE FREE-OPENING, UNVENTED CASE, $\beta = 10°$, $V = 50.0$ FPS

12
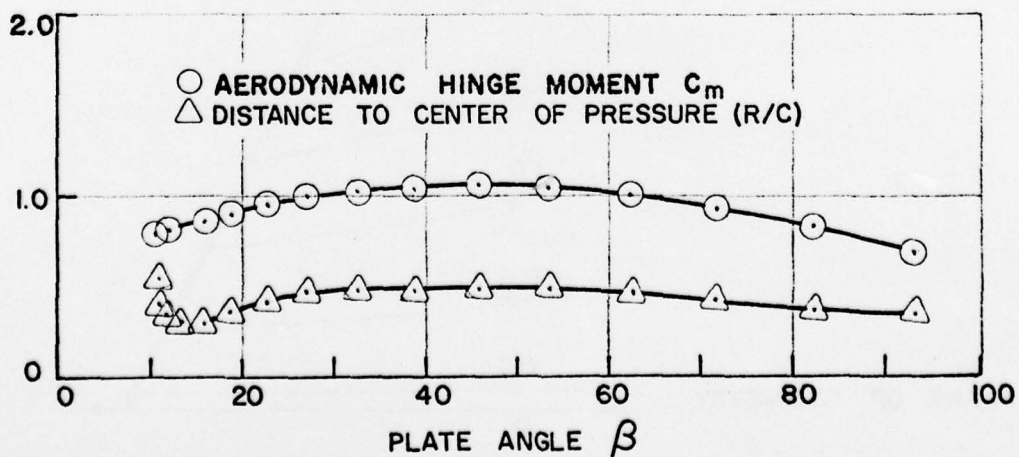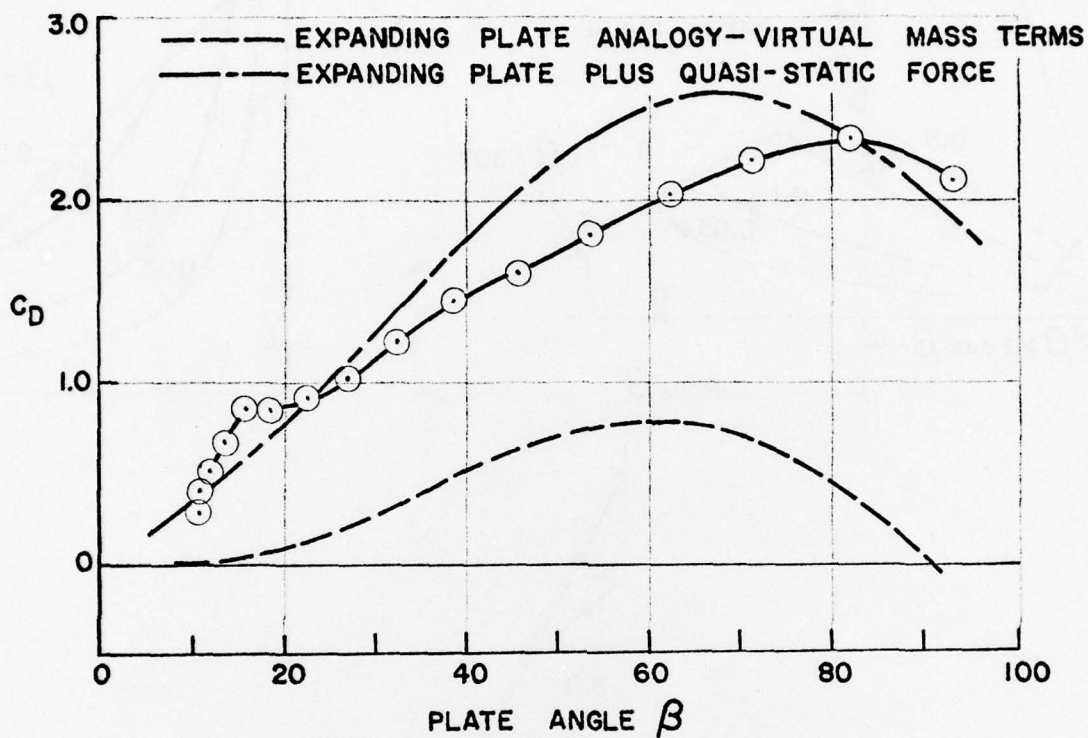
FIGURE 10. TRANSIENT DRAG OF A FREELY OPENING PLATE, BASE VENTED, 50 FPS
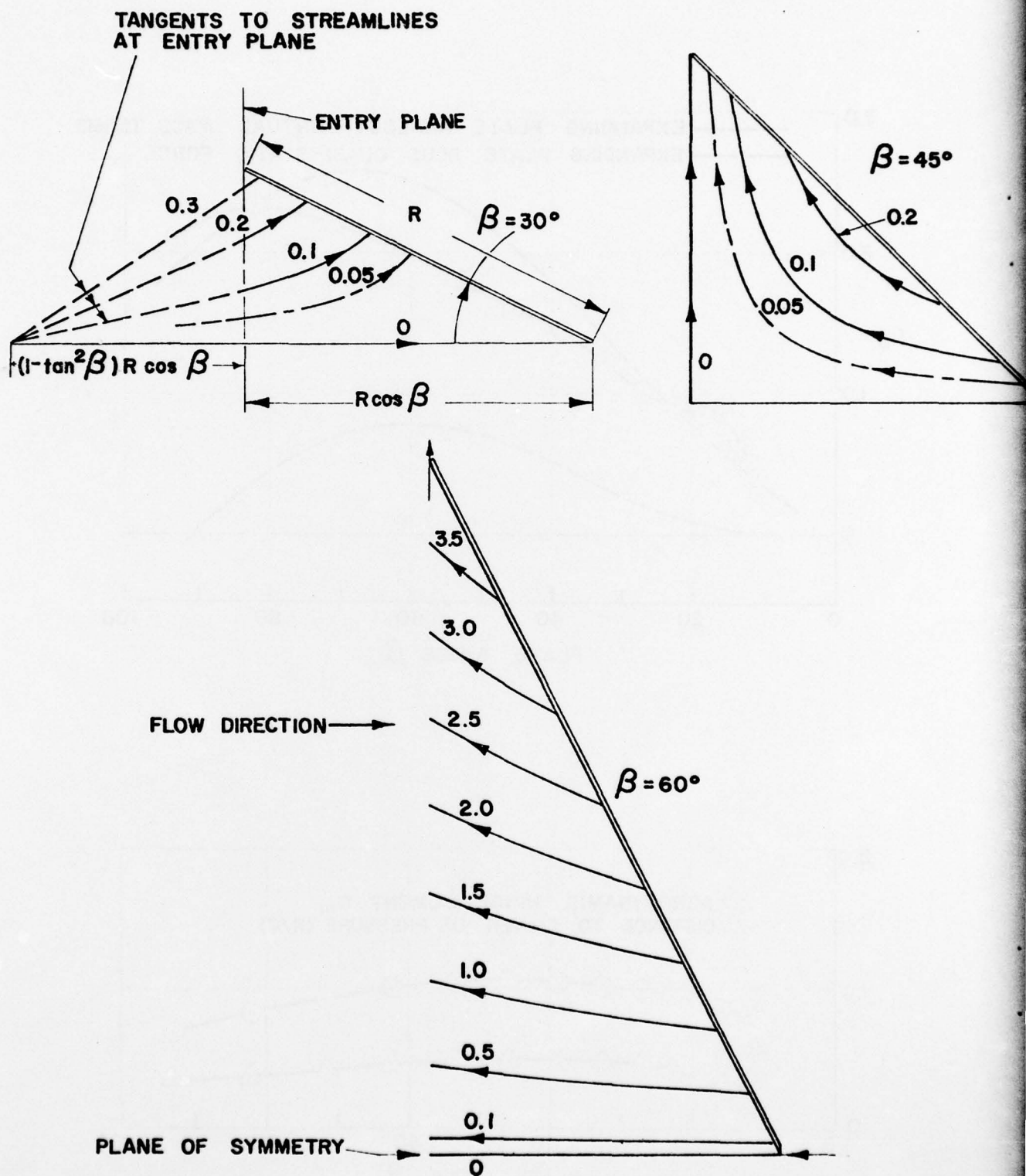TUNNEL SPEED, INITIAL ANGLE = 10°.

13

FIGURE 11. STREAMLINES IN A GUTTER WHEN THE FORWARD EDGE IS CONSTRAINED FORE
AND AFT, AND THE VERTEX IS FREE TO MOVE ALONG THE AXIS. IN THE
PLOTS $R \cos \beta$ IS TAKEN AS UNITY AND THE VALUES ON THE CURVES ARE
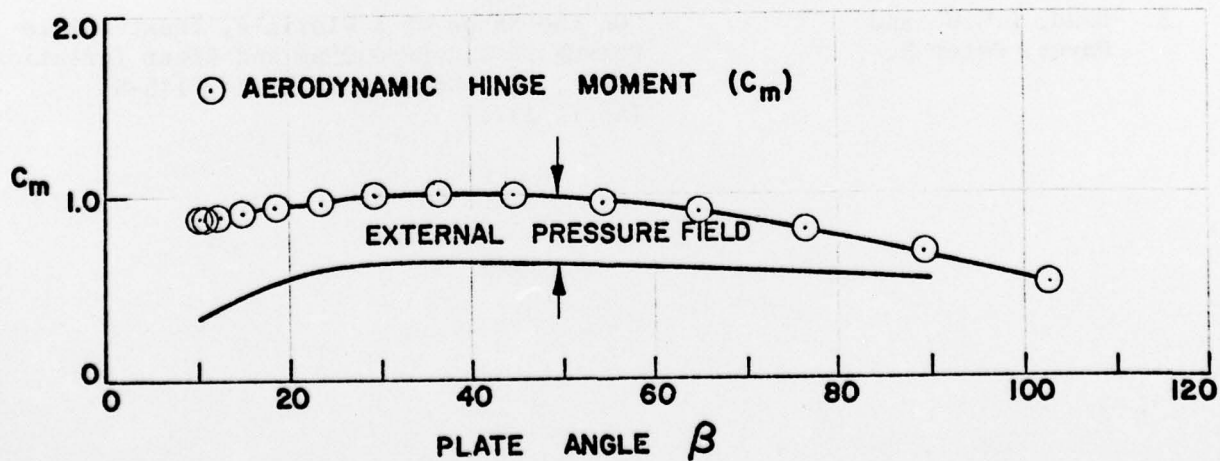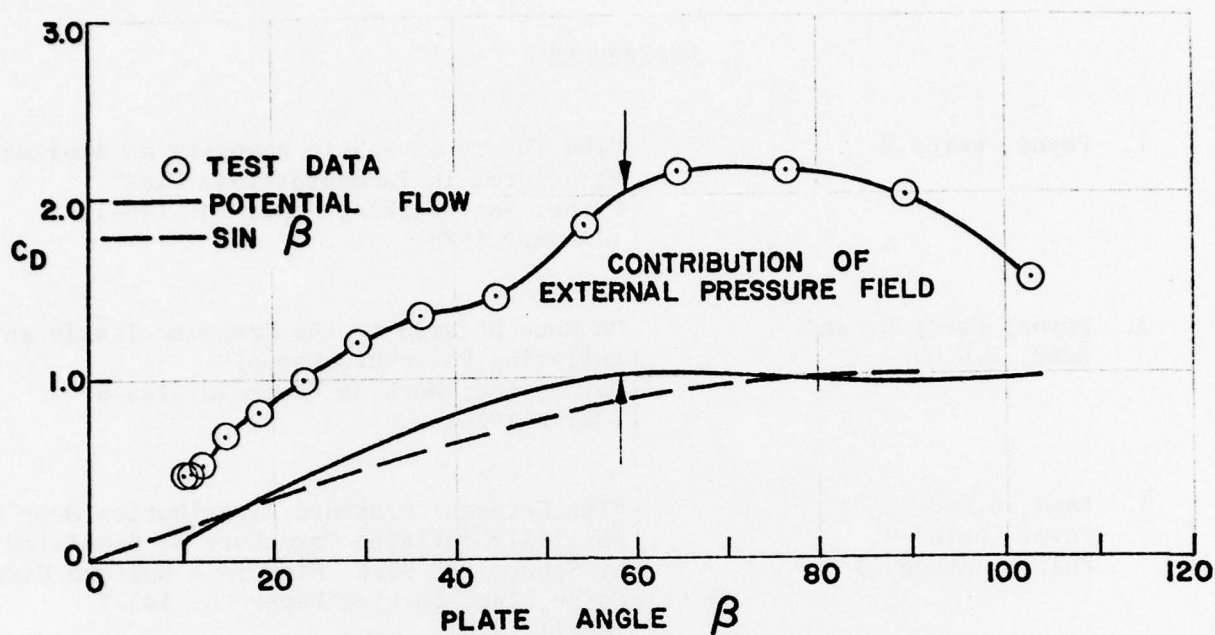$C/R^2 \cos^2 \beta$

FIGURE 12. THE INTERNAL POTENTIAL FLOW SOLUTION COMPARED WITH THE
WIND TUNNEL MEASUREMENTS

REFERENCES

1. Payne, Peter R.

   "The Theory of Fabric Porosity as Applies to
   Parachutes in Incompressible Flow"
   Payne, Inc. Working Paper No. 145-1
   (January 1976)

2. Payne, Peter R. and
   Band, E.G.U.

   "A Note Related to the Pressure Inside an
   Inflating Parachute Canopy"
   Payne, Inc. Working Paper No. 145-9
   (March 1976)

3. Band, E.G.U.
   Payne, Peter R.
   Euler, Anthony J

   "The External Pressure Distribution Over a
   Partially Inflated Parachute as Simulated
   by Source and Sink Flow in a Uniform Stream"
   Payne, Inc. Working Paper No. 145-3
   (April 1976)

4. Klimas, Paul C. and
   Rogers, David F

   "Helium Bubble Survey of a Parachute Opening
   Flowfield Using Computer Graphics Techniques"
   for U.S. Army NATICK Laboratories, (May 1975)
   Also published as AIAA Paper No. 75-1368
   (November 1975)

5. Band, E.G.U. and
   Payne, Peter R.

   "On the Shape of a Flexible, Inextensible
   Parachute Canopy During and After Inflation"
   Payne, Inc. Working Paper No. 145-5
   (April 1976)

APPENDIX

SIGNIFICANT REPORTS GENERATED
UNDER CONTRACT NO. F44620-76-C-0020
TO DEVELOP THE THEORY OF PARACHUTE OPENING

Working Paper No.	Author(s)	Title
145-1	P.R. Payne	The Theory of Fabric Porosity as Applied to Parachutes: Part I - Incompressible Flow, November 1975.
145-3	A.J. Euler E.G.U. Band P.R. Payne	The External Pressure Distribution Over a Partially Inflated Parachute as Simulated by Source and Sink Flow in a Uniform Stream, April 1976.
145-5	P.R. Payne E.G.U. Band	On the Shape of a Flexible, Inextensible Parachute Canopy During and After Inflation, December 1975.
145-6	P.R. Payne	The Total Head Loss Due to the Suspension Lines of an Inflating Parachute Canopy in Incompressible Flows, January 1976.
145-7	P.R. Payne	Notes on the Taylor Parachute Shape Equation, January 1976.
145-8	P.R. Payne	On a Class of Nonlinear Second Order Equations, February 1976.
145-9	P.R. Payne	A Note Related to the Pressure Inside an Inflating Parachute Canopy, March 1976.
145-10	P.R. Payne	A Note on the Quasi-Static Flow into a Parachute Canopy, January 1976.
145-11		A Bibliography Related to Parachute Opening, March 1976.
145-12	P.R. Payne F.W. Hawker	The Fluiddynamic Forces Acting on a V-Gutter, Free to Open About a Pivot at its Vertex: A Theoretical and Experimental Investigation, November 1976.
145-13	P.R. Payne E.G.U. Band	Final Report - Research on Parachute Opening, November 1976.

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER AFOSR - TR - 77 - 0317	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes work carried out under contract number F44620-76-C-0020 in connection with parachute opening theory. Contributions were made in the following areas: (a) Prediction of fabric porosity effects; (b) Calculation of the external and internal pressure fields during inflation; (c) Calculation of the canopy shape and stress distribution during inflation.

These three elements, taken together, cover the problem, but they were not integrated into a complete predictive methodology because of lack of time.

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The analogous problem of the opening of a two-dimensional hinged plate was also studied, both experimentally and theoretically. The problem of the inviscid flow field inside such an inflating wedge was solved exactly, in closed form, and agreed well with experiment.

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